

## DISPLAY DEVICE FOR INFRARED IMAGING

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### Abstract

This paper describes the operation of multi-element Glow Modulator Tubes developed for infrared imaging. Several IR imaging systems are outlined and the advantages of the Glow Modulator Tube are detailed in relation to the more conventional cathode ray tube display. Electrical and photometric characteristics are discussed. Other potential applications of the Glow Modulator Tube to multi-channel, real-time displays are suggested.

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## INTRODUCTION

Infrared technology has developed rapidly in the last two decades. The principal impetus has come from military applications but the "fall-out" into other areas has been extensive. In such diverse fields as medicine, the earth sciences, and industry, the use of IR sensing is fast developing.

## SINGLE-SENSOR CRT SYSTEMS

In many applications, an infrared image must be presented as a visible picture. Presently, there are commercially available a number of infrared cameras for this purpose. Figure 1 illustrates one such system. The fast horizontal scan is provided by a rotating multi-faceted mirror and the vertical scan by a slower-moving tilting mirror. As the mirrors scan the object, an IR detector senses the radiation and modulates the intensity of a cathode ray tube whose vertical and horizontal deflection circuits are triggered from signals derived from the scanning mirrors. The speed and sensitivity of such systems depend upon the detector. Typically, such a system may have a thermal sensitivity as high as  $.2^{\circ}\text{C}$  and a refresh rate of a few frames per second.

## MULTI-SENSOR CRT SYSTEMS

A single-sensor camera is limited by the IR detector. To increase the speed and/or sensitivity, systems utilizing multi-detector arrays have been developed. By providing linear arrays of detectors, the need for a scanning mirror in one of the axes is eliminated. A typical system of this type is illustrated in Figure 2.

An oscillating mirror provides the vertical scan. Each sensor in the horizontal axis is sampled once for every equivalent horizontal line. The multi-

plexed IR signal modulates the intensity of the CRT which displays the IR image. Again, the vertical and horizontal deflection circuits of the display are appropriately synchronized with the mirror and the electronic multiplexer. These systems are typically capable of fifteen or more frames per second.

#### MULTI-SENSOR GLOW MODULATOR TUBE SYSTEMS

The IR imaging systems utilizing CRT's have basic limitations imposed by the cathode ray tube itself. The characteristics of the phosphor screen present the most serious problem. As the brightness of a spot is increased, the spot size also increases and, consequently, compromises the resolution of the system. Optical crosstalk within the phosphor and halo can also be serious since they limit the gray-scale range of the display.

Burroughs Corporation has overcome these problems by designing a display tube which eliminates both optical crosstalk and blooming of the spot size. This has been accomplished by providing an array of glow cavities in a single envelope. Each cavity is capable of independent modulation, is optically isolated from its neighbors, and is provided with an aperture mask which defines precisely the shape and dimensions of the display element.

Figure 3 shows the outline of one version of the Glow Modulator Tube. All the tubes have the same general construction except for the number of cathodes. Each has a common anode, a common glow focusing electrode, and a discrete number of cathodes. The cathodes are mounted inside cavities formed in the glow focusing electrode. The anode contains precise apertures through which the glow inside the cavities is viewed. The cavities are arranged in a staggered array so that a wall can be maintained between the cavities, thereby

eliminating optical crosstalk. Along each row, the aperture dimension is one-half the center to center spacing of the cavities in the row. In the display, the raster lines generated by the two staggered rows are interlaced; thus providing a substantially continuous field. Figure 4 illustrates a multi-sensor system which utilizes a Glow Modulator Display Tube. An oscillating mirror scans the field of view and focuses the IR radiation on the detectors. Each individual detector converts the IR energy to an electrical signal which, when suitably amplified, is used to modulate the brightness of the corresponding cavity of the Glow Modulator Tube. A second mirror scans the Glow Modulator Tube and provides the visible raster display of the original infrared image. It is usually mounted back-to-back with the objective mirror and is, therefore, strictly synchronous. It should be noted that an infrared imaging system is, because of economic necessity, resolution limited. It is important that the available resolution be conserved in the display. In a cathode ray tube system, some of the information content, in spatial frequency terms, can be lost due to the variable brightness profile of the CRT spot. In a Glow Modulator Tube System, the geometrical bandwidth in the scanned direction can be tailored, at some expense to the average display brightness, by reducing the dimension of the display aperture in the direction of scan.

#### OPTICAL CHARACTERISTICS OF THE GLOW MODULATOR TUBE

The Glow Modulator Tubes are filled with a Neon gas mixture. The spectral output is characterized chiefly by the Neon gas. This results in a visible display in which the gray scale is generated in shades of orange-red. Each cathode can be independently current-modulated to provide an instantaneous brightness range from approximately 5 footlamberts at the lowest current of  $2\mu\text{A}$  to more than 10,000 footlamberts at the rated peak current of 3.5 mA. The

dynamic brightness range that can be attained depends on the relative scan length. For instance, let the following conditions be assumed:

- (1) A scanned length equivalent to 150 aperture elements.
- (2) A scan efficiency of 75 percent.
- (3) A required quiescent brightness of .5 fL.

Under these conditions, the equivalent instantaneous brightness of a cavity would be  $\frac{.5 \times 150}{.75} = 100 \text{ fL}$ .

Thus, the peak brightness of 10,000 footlamberts would permit a maximum brightness ratio of 100, providing at least thirteen distinct shades of red, if we assign shades in terms of the power of  $\sqrt{2}$ .

Figure 5 illustrates the brightness transfer function for 25 cathodes. At the high end, the average brightness varies by approximately plus or minus 25 percent. Figure 6 shows the same group of cathodes which have been normalized by trimming the drive circuits. While the absolute magnitude of the brightness varies from cavity to cavity, the shapes of the transfer functions are similar and can be made to track. In recent tubes, the geometrical uniformity of the tubes has been improved and these tubes have shown considerably better brightness uniformity. It is expected that it will be possible to maintain absolute variations such that the scanned-out field will have good uniformity without any need for individual channel equalization.

At low current values, due to the negative slope of the volt-ampere characteristic, the Glow Modulator Tube exhibits current oscillation. The frequency of the oscillation is generally greater than that which can be reproduced by the scanning aperture. It can, however, cause anomalous jumps in the integrated brightness transfer function. When the glow focusing electrode is connected

to anode, oscillation occurs at about  $15\mu\text{A}$ . When the glow focusing electrode is biased negatively with respect to anode, the current range over which oscillation occurs increases. At  $-22\text{V}$ , this oscillation may occur at a cathode current up to  $25\mu\text{A}$ .

The magnitude of the oscillation and, therefore, the effect on the transfer function depends on the parasitic capacitance of the device and circuits. It is recommended, for minimal jumps in the brightness transfer function, that the glow focusing electrode be connected directly to anode. It will be noted that in so doing, the brightness of the individual cavities will be reduced approximately 10 percent on average, below the value observed when tested at a Glow Focusing Electrode bias of  $-22\text{V}$ . While a bias voltage on the glow focusing electrode has a detrimental effect with regard to the oscillation, it does improve the linearity of the brightness transfer function over the full current range. It also tends to improve the light distribution within the aperture.

#### ELECTRICAL CHARACTERISTICS AND DRIVE CIRCUITRY

Electrically, the Glow Modulator Tubes are very similar to other cold cathode gas discharge display tubes such as the Burroughs NIXIE<sup>®</sup> numeric indicator tube. The breakdown voltage of each cavity depends on the bias applied to the glow focusing electrode. At zero bias, the breakdown voltage is approximately 140 volts while at  $-22\text{V}$ , the nominal test condition, it averages 165 volts. The minimum power supply voltage should be no less than the maximum breakdown voltage. This is specified as 200 volts. With a supply voltage of 200 volts, the peak current that can be drawn is approximately 1.3 mA. This peak current can be increased by increasing the supply voltage in a linear fashion to the 3.5 mA rated peak current at a tube voltage of 260 volts.

Presently, individual cathodes of the Glow Modulator Tube family are rated for a maximum pulse duration of 2.5 milliseconds with a 5 percent duty factor and a peak current of 3.5 mA. Tubes have been life tested successfully under these conditions for over 500 hours. They have also been life tested under static conditions at .5 mA per cathode for over 3,000 hours. It has been found that, when the pulse duration at high current is too long, detrimental effects can occur even when the duty factor is conservative. For example, in our initial life test, a pulse duration of one second (at 5% duty factor) brought on tube failure after only 24 hours of operation. At intermediate conditions, the life of the tube is unknown. Studies are continuing to determine the maximum practical pulse duration that can be specified while still maintaining good life. In the systems in which the Glow Modulator Tube has been used, the peak currents required have only been a fraction of the rated value. It is expected that in these actual applications, the life of the tube will be excellent.

Figure 7 shows a schematic diagram of a tube drive circuit which uses high-voltage current repeaters. The transistors used in this circuit should be selected for a minimum breakdown voltage of 250 volts and a maximum leakage current of .5  $\mu$ A at 250 volts. Each cathode is also returned through a 22-megohm resistor to an appropriate voltage so that a "keep-alive" current of 2 to 5  $\mu$ A is maintained in the cavity to prevent deionization.

The power supply voltage that must be used depends upon the required peak current as previously indicated. If the voltage is low, then it is possible to reduce the breakdown voltage requirement for the drive transistors. In theory, this rating should not have to be greater than the difference between

the maximum supply voltage and the minimum sustaining voltage. The minimum sustaining voltage at the minimum rated current of 2  $\mu$ A is approximately 120 volts. However, a conservative transistor specification is desirable.

#### APPLICATION FEATURES

The Glow Modulator Tube is a new and promising display device. It is small in size and very rugged. It has relatively low voltage and power requirements. It has high dynamic brightness capability, and it interfaces directly with parallel low bandwidth circuitry. All these features make it an effective component in infrared imaging systems.

The Glow Modulator Tube's direct compatibility with multi-channel data systems suggest its use as a real time display in such other applications as:

- Medical transducers
- Strain gauges
- Thermocouples
- Pulse height or spectrum analyzer bins
- Statistical distribution classifiers

#### ACKNOWLEDGEMENTS

Particular versions of the Glow Modulator Tube have been developed in close cooperation with Hughes Aircraft Company and Raytheon Corporation. Continued tube studies as well as the study of certain system aspects are being supported by the Night Vision Laboratory of the United States Army Electronics Command under Contract DAAK 02-67-C-0113. Burroughs Corporation is grateful for the support and confidence of the users of the Glow Modulator Tubes.



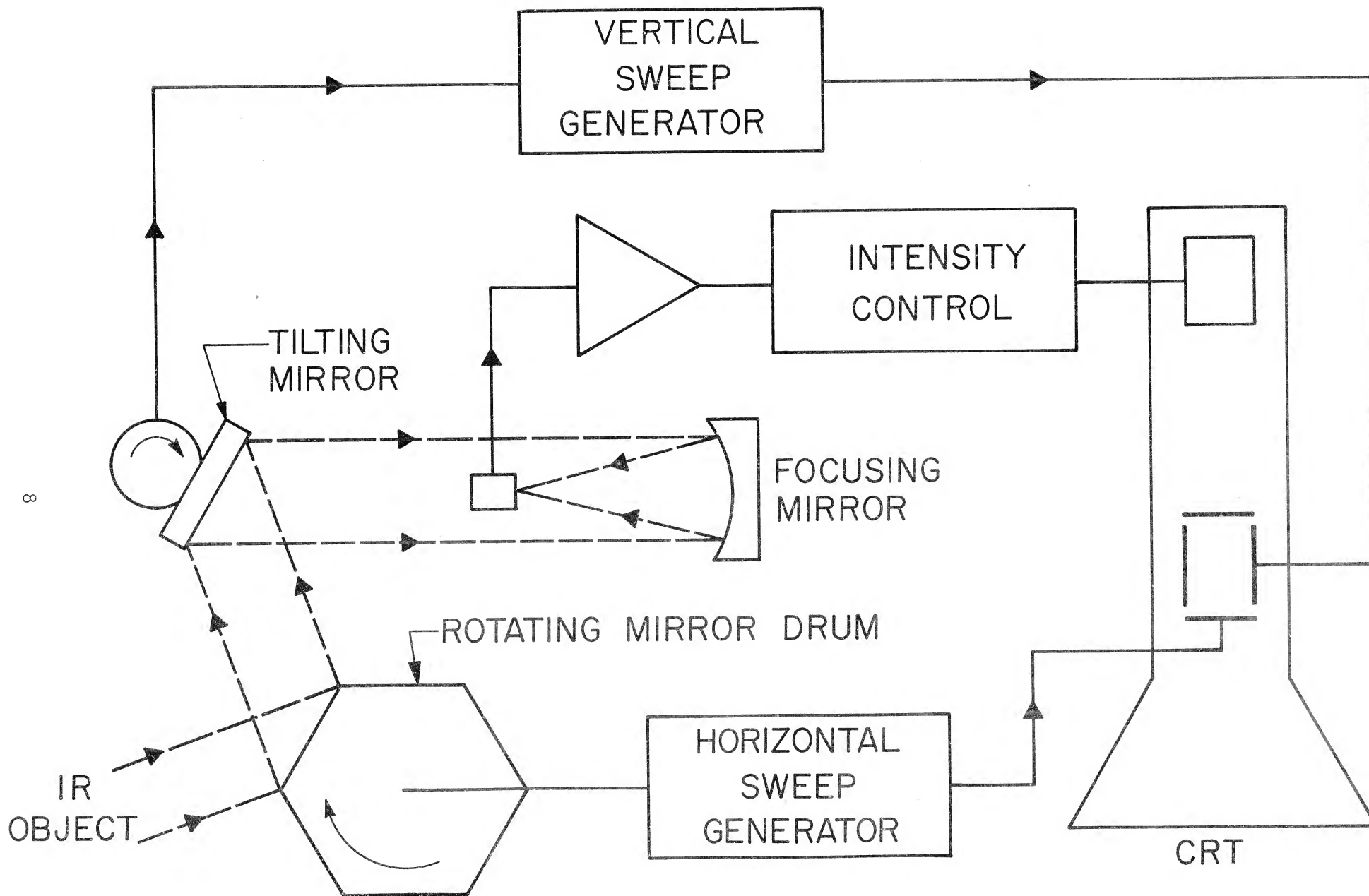


Figure 1. Single-Sensor CRT Display

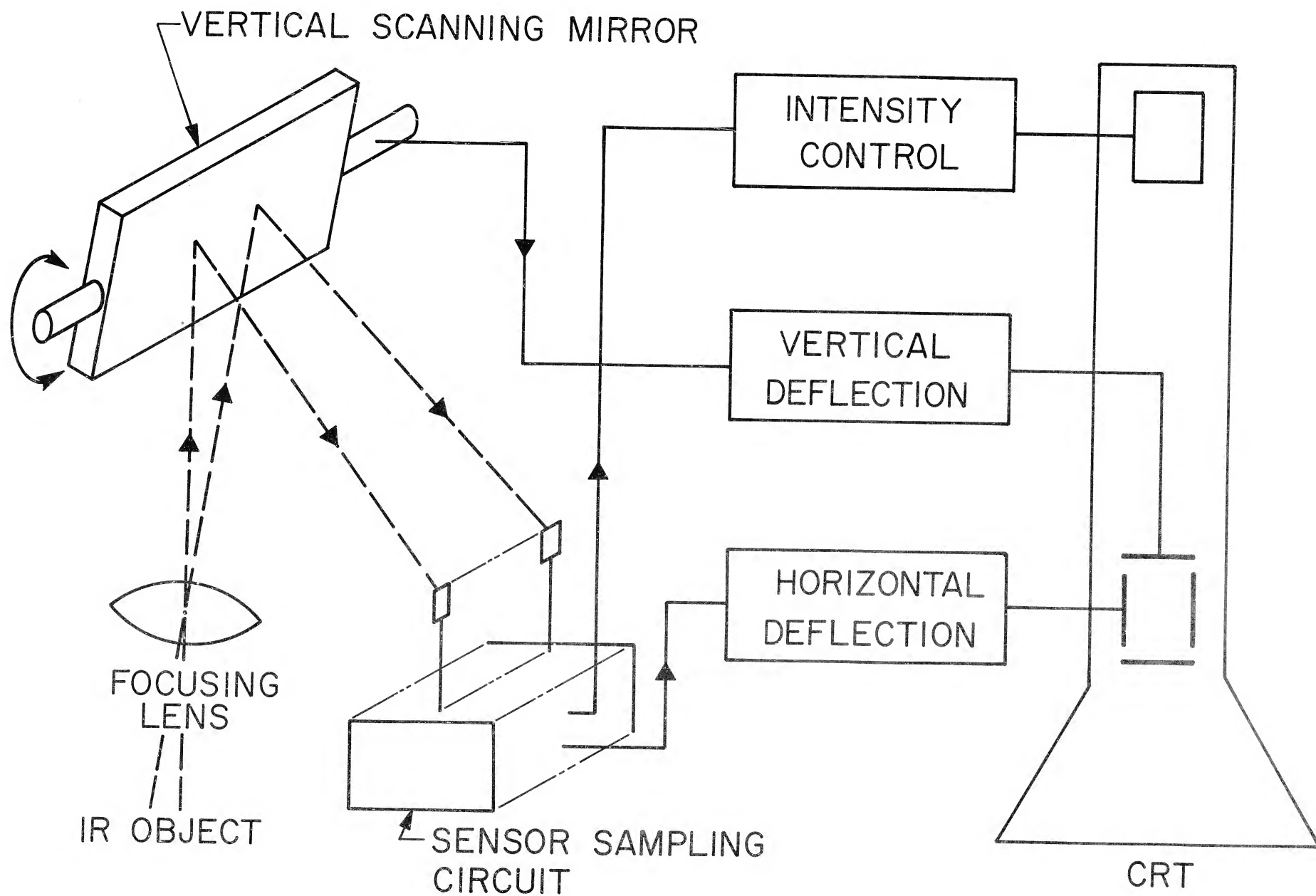


Figure 2. Multi-Sensor CRT Display

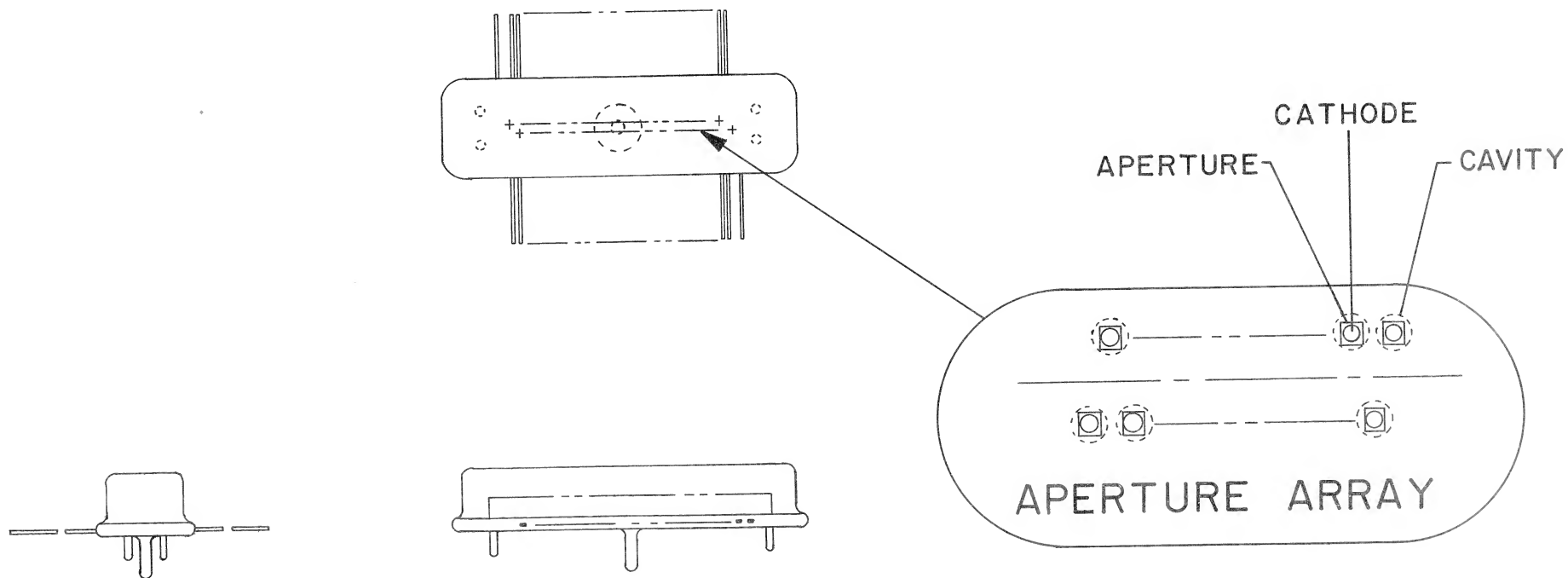


Figure 3. Glow Modulator Tube Outline

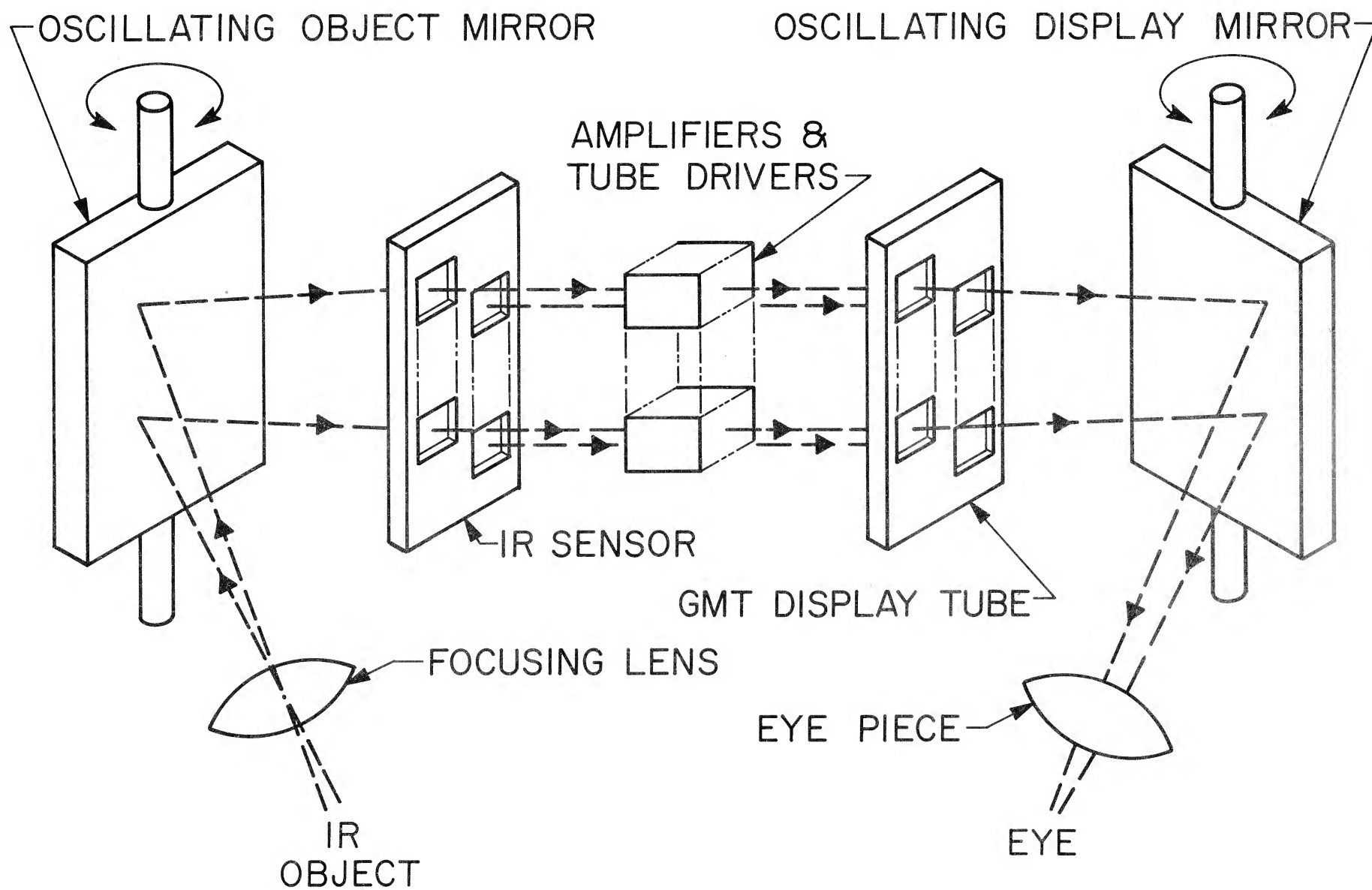


Figure 4. Multi-Sensor Glow Modulator Tube Display

BRIGHTNESS (FOOTLAMBERTS)

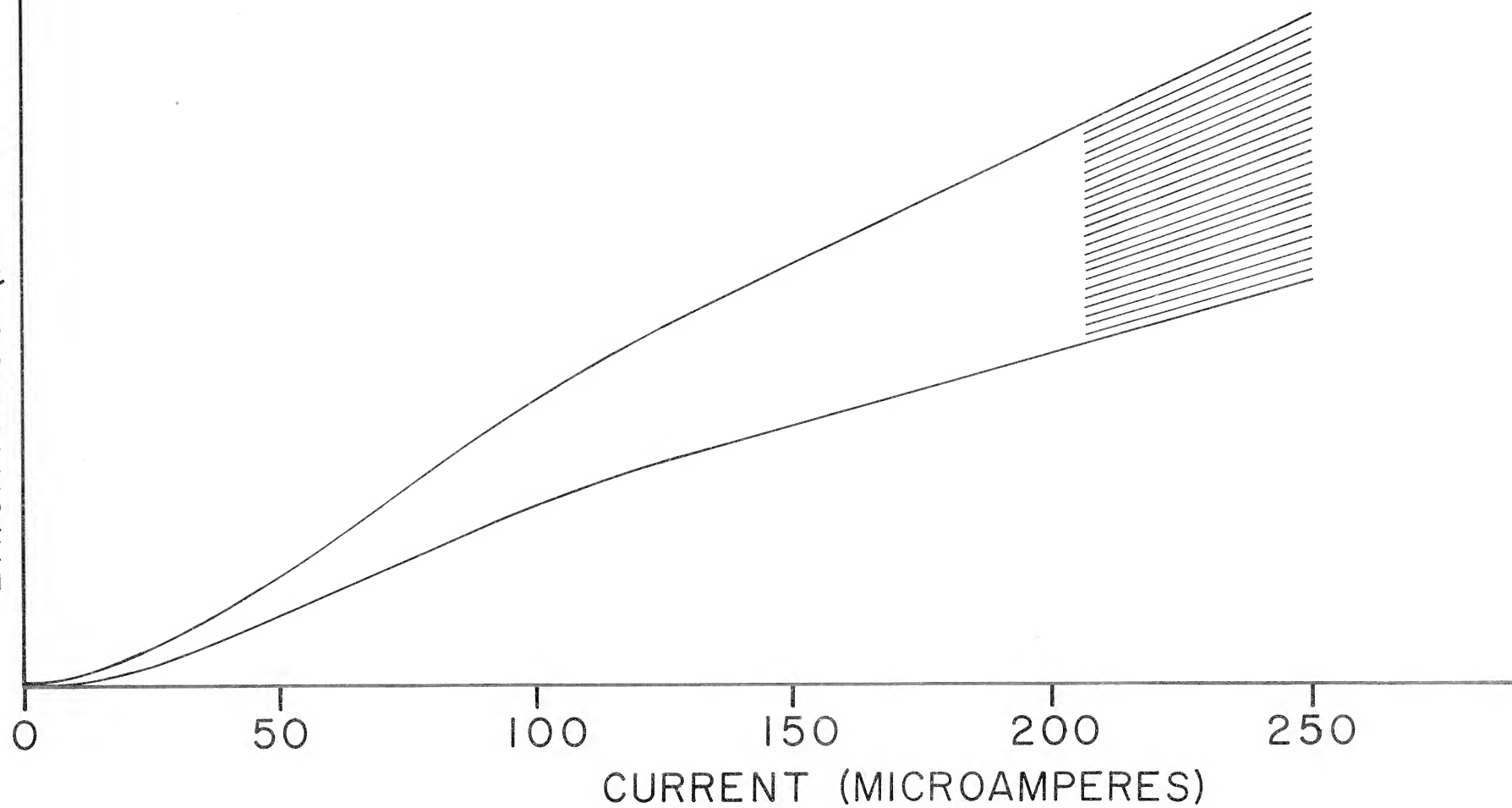


Figure 5. Brightness Transfer Function of 25 Cathodes

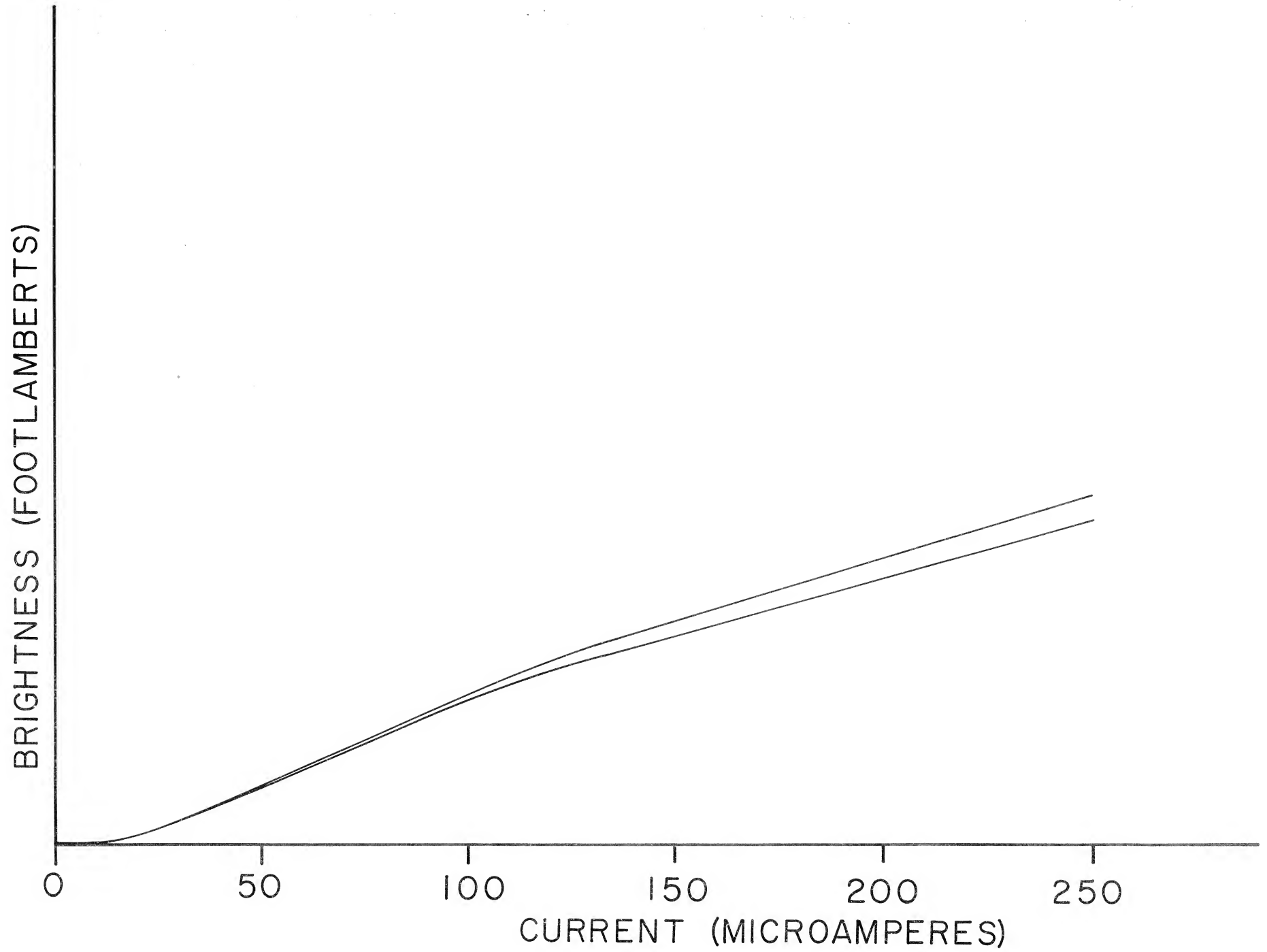


Figure 6. Brightness Transfer Functions of 25 Cathodes,  
Normalized

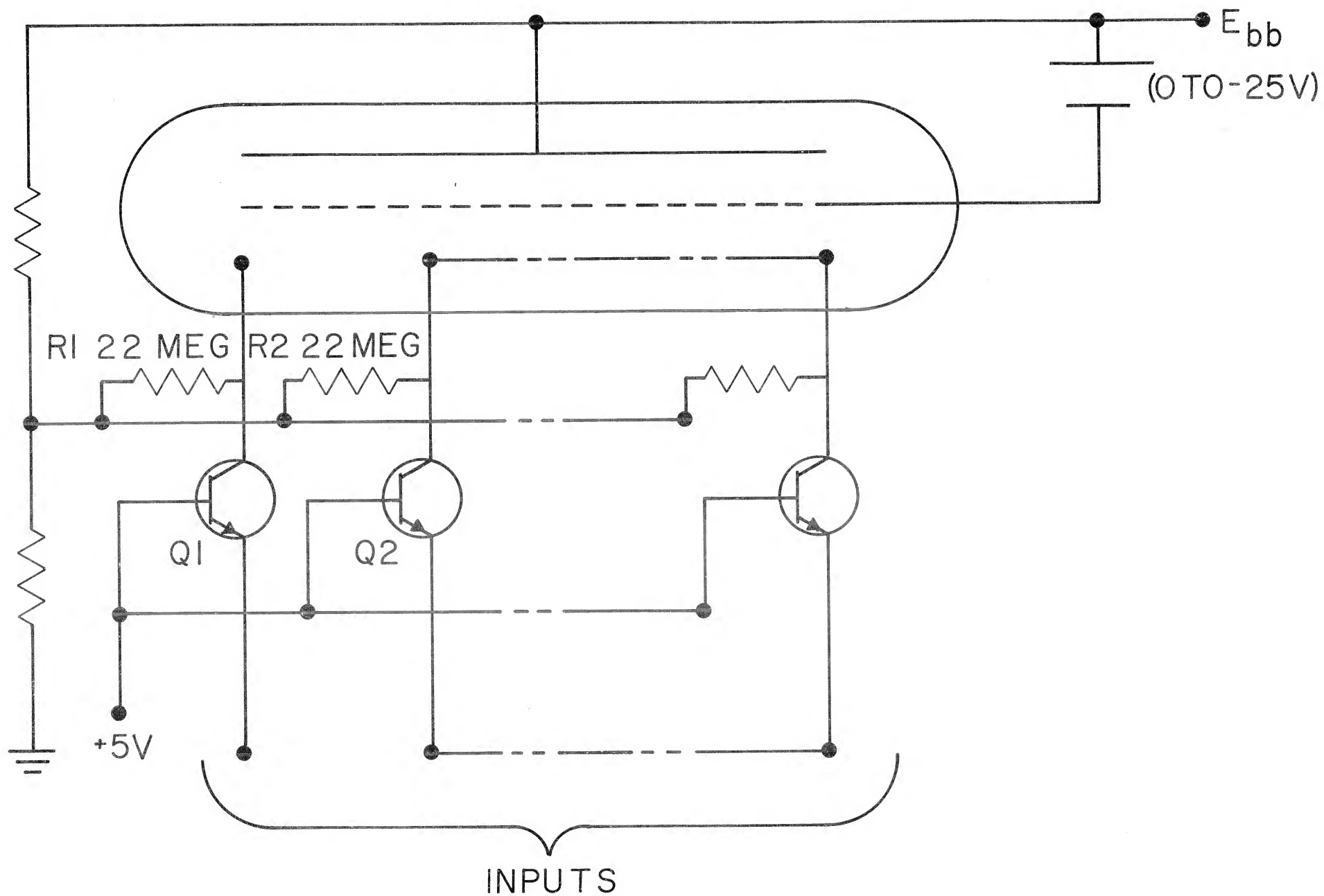


Figure 7. Glow Modulator Tube Driver Circuit